Pioneer Mission Support

A. J. Siegmeth
Mission Support Office

The Pioneer F and G missions are planned to extend the exploration of the solar system toward the outer planets. The major objectives will be the first penetration of the asteroid belt and a Jupiter flyby. Since Jupiter missions require new types of solar orbits, some adaptations of the tracking and data acquisition capabilities and resources are necessary to meet effectively the requirements of these new challenges. The Pioneer F and G mission characteristics and the near-Earth and deep-space phase support plans are delineated in this article.

I. Introduction

Currently, the Deep Space Network is engaged in intensive testing and training activities to prepare for the launch of the *Pioneer F* mission. The launch window of *Pioneer F* will open on February 27, 1972 and will close on March 13, 1972. The *Pioneer F* mission is NASA's first attempt to expand the exploration of the solar system into the direction of the asteroid belt and Jupiter, thus making a dynamic step toward the outer planets.

In the previous issues of the DSN Progress Reports (Refs. 1 through 5), a description was given of the *Pioneer F* and G mission profiles and spacecraft design and spacecraft attitude control, with special emphasis on tracking and data acquisition interfaces. The last two articles described configuration and data flow of the six DSN systems comprising the DSN Mark III, as they will be configured for the support of the *Pioneer F* and G missions.

II. Launch Profile of *Pioneers F* and G

Every 13 months, the relative positions of the Earth and Jupiter permit a spacecraft to be launched into a Jupiter-bound trajectory with minimum launch energy.

It is planned to inject *Pioneer F*, carrying 11 scientific instruments, into a Jupiter-bound orbit with an *Atlas/Centaur*/TE-M-364-4 launch vehicle. Consistent with current values of spacecraft weight, launch vehicle performance and the southerly azimuth limits (between 94.5 and 110 degrees east of true north), the *Pioneer F* launch period begins on February 27, 1972 and lasts for 16 days. (The daily launch window is in the vicinity of 30 minutes.) This limitation is associated with characteristics of a direct ascent powered flight profile. A typical opening time of the 30-minute-long daily launch opportunity will be between 20 hours and 50 minutes EST at the end of February, and 19 hours and 10 minutes EST during the first part of March. *Pioneer G* will be launched during April 1973.

The typical time of 650 days to Jupiter encounter will be achieved with a February 27, 1972 launch date. This trajectory will result in a Jupiter arrival date of December 8, 1973. If the spacecraft is launched on March 3, 1972 a shorter trip time of 631 days can be obtained with a Jupiter arrival date of November 24, 1973. With a launch date of March 13, 1972 the voyage will take 766 days with an estimated arrival date at Jupiter on April 18, 1974. The closest distance between Jupiter's center and the spacecraft will be in the vicinity of three Jupiter radii. The periapsis distance will be approximately 140,000 kilometers measured between the optical surface of the planet and *Pioneer F*.

The rationale for choosing the daily launch trajectories was determined by numerous factors. The launch azimuth constraint determined the boundaries of the near-Earth trajectories. The shorter Jupiter trip times were favored against the longer ones. Trajectories that were bringing the S-band radio beam too close to the solar corona were eliminated. This measure was necessary because of the degradation of the telecommunications link's signal-to-noise ratio caused by solar noise. In addition, efforts were made to share the available resources of the Deep Space Network between the *Pioneer F* Jupiter encounter and the *Mariner* 1973 Venus and Mercury flybys. The view limitations of some onboard *Pioneer F* scientific instruments and the objective to have an S-band signal occultation by Jupiter were factors that determined the angle of the aiming point at Jupiter and its position in relationship to the planet's spin axis and equator. To reach the planned Jupiter flyby aiming point within a predetermined dispersion, two or possibly three midcourse or trim maneuvers will be necessary to alleviate the aiming errors of the launch vehicle.

III. Tracking and Data Acquisition Support

The Jet Propulsion Laboratory, as the Tracking and Data Acquisition Center for the *Pioneer F* and *G* missions, is responsible for obtaining the support of available NASA and other U.S. Government-operated facilities necessary to assure near optimum data return, very reliable spacecraft control, and precision navigation. It is planned to make available the following facilities and resources for *Pioneers F* and *G*:

(1) *The Deep Space Network* (DSN), operated for NASA by the Jet Propulsion Laboratory, provides capabilities for deep space tracking, telemetry data acquisition, and command, and also provides operational facilities and some ground communications capabilities.

(2) *The NASA Communications Network* (NASCOM), operated for NASA by the Goddard Space Flight Center (GSFC), provides worldwide ground communications circuits and facilities as required.

(3) *The Goddard Space Flight Center* (GSFC) provides near-Earth tracking and data acquisition capabilities as required.

(4) *The Air Force Eastern Test Range* (AFETR), operated for the Department of Defense by the National Range Division of the Air Force, provides tracking and data acquisition and some communications support during the near-Earth phase as required.

(5) *John F. Kennedy Space Center* (KSC) provides prelaunch and launch support.

(6) *The JPL Scientific Computing Facility* (SCF) provides analysis program operations on one of two Univac 1108 computers.

IV. Near-Earth Phase

Based on *Pioneer* Project's launch requirements, several near-Earth phase tracking and data acquisition facilities will participate during the launch of *Pioneers F* and *G*. Provisions will be made for telemetry and radio metric tracking of the three stages of the launch vehicle and for the collection of real-time telemetry from the spacecraft during powered flight. The launch vehicle-generated information is necessary to monitor the performance of the launch vehicle system to determine any deviations from normal performance predictions and to generate a solar orbit injection velocity vector. This near-real-time orbit information is necessary so that the Deep Space Network can obtain antenna angle and frequency predictions for efficient first-signal acquisition. The real-time spacecraft telemetry furnished by the near-Earth phase tracking facilities will be provided for the Project's Mission Operations Systems team to monitor the powered flight performance of the spacecraft to check for normalcy, and prepare for the transmission of important commands after the first two-way signal acquisition by the DSN.

The following Air Force facilities of the Eastern Test Range will be involved in the near-Earth phase of the *Pioneer F* mission:

(1) Merritt Island radar.

(2) Grand Turk radar.

(3) Antigua radar and telemetry.

(4) Ascension radar and telemetry.

In addition, the following Goddard Space Flight Center Stations plan to support the near-Earth phase activities:

(1) Merritt Island USB Station.

(2) Bermuda.

(3) Canary Islands.

(4) Ascension USB Station.

(5) Tananarive.

(6) *Apollo* Instrumentation Ship, *Vanguard.*

During the launch operations, the spacecraft will operate in the following configuration: The telemetry bit rate to be used will be 128 bits per second and the engineering telemetry will be transmitted by the spacecraft in the real-time mode. Since the near-Earth phase support facilities have no sequential decoding capabilities, the spacecraft's convolutional encoder will be turned off. The traveling-wave tube (TWT) amplifier of the spacecraft's telecommunications package will be turned on and will operate with the full power output, which will be radiated toward the ground by the omni/medium-gain antenna system. All experiments will be turned off during launch operations.

Figure 1 displays the typical Earth tracks of *Pioneer F* launches. Since the launch azimuth has to be changed for every day's launch opportunity to obtain the planned solar orbits, the Earth tracks of the launch trajectories cover a band approximately 2500 kilometers wide. The locations of the launch vehicle's main engine cutoff (MECO), end of third stage burn, and Ascension and Johannesburg rise are indicated.

Figure 2 displays the launch sequence of events after the launch. The signal visibility rise and set times at the corresponding near-Earth stations are given. This coverage chart shows that no data can be obtained from Antigua or Ascension on the third stage burnout (BO) and the subsequent 3 minutes of flight. To fill this gap it is planned to station the *Apollo* instrumentation ship, *Vanguard,* at a predetermined location to assure continuous spacecraft telemetry from launch up to the first DSN acquisition, and also obtain radio metric data on the injection.

The signal visibility rise times of the Ascension station (GSFC), DSS 51 in Johannesburg, and DSS 61 in Madrid are shown for four typical launch dates on Fig. 3. The Ascension rise time is approximately 15 minutes and 45 seconds after launch. DSS 51 in Johannesburg will see the spacecraft starting at 21 minutes after launch. However, because of the low declination angles, DSS 61 in Madrid will see the spacecraft only between 29 and 63 minutes after launch. Since the Flight Project hopes to obtain a two-way telecommunications link lock not later than 26 minutes after launch, the decision was made to use DSS 51 as the prime first DSN signal acquisition station. The Goddard Space Flight Center's Ascension station will be used as a full backup of DSS 51. Both stations will see spacecraft events controlled by an onboard automatic sequencing system.

After the two-way lock has been established with the spacecraft, the near-Earth phase of the mission is completed and the deep space phase of the mission begins. The deep space phase of the mission ends when the mission is terminated.

The typical *Pioneer F* launch vehicle/spacecraft altitude and velocity profiles during the power flight are given in Fig. 4. The injection velocity of the spacecraft is 14 kilometers per second—the highest Earth-referenced velocity applied in NASA's planetary program. To illustrate the dynamics of a Jupiter-bound mission trajectory, it should be pointed out that *Pioneer F* will cross the Moon's orbit in 11 hours, Mars's orbit in 2½ months, and will encounter Jupiter in 650 days. These event times provide a graphic picture of the spacecraft's velocity and the tremendous distance to Jupiter.

The corresponding uplink doppler shift and doppler rate of the S-band uplink carrier, as seen at DSS 51 after injection, is shown in Fig. 5. The uplink doppler shift, caused by the relative movement between spacecraft and DSS 51 antenna in Johannesburg at 22 minutes after launch, is plus 10 kHz. However, at 30 minutes, the doppler shift is down to minus 60 kHz, and, later, below minus 70 kHz. The rate of this doppler shift at the time the uplink signal will first reach the spacecraft is around minus 220 Hz per second. This rate drops to minus 50 Hz per second around 30 minutes after launch. Because the spacecraft receiver has a maximum doppler rate capability of 150 Hz per second, it can only lock on the station's uplink S-band signal 25 minutes after launch, or later. After checking out the performance of the two-way links, the Projects can send the first command at 30 minutes after launch. Since the Project wants the capability to change some of the flight sequences as early as possible, DSN plans to attempt a two-way lock with a command capability as early as 26 minutes after launch on a best-effort basis.

V. Deep-Space Phase

The *Pioneer F* and *G* spacecraft carries 11 onboard instruments, many of which have the capability of collecting continuous cruise science information. Therefore, the *Pioneer* Project requires an almost continuous tracking and data acquisition support from launch to the end of the Jupiter encounter's exit phase. The DSN plans to furnish almost 24-hour/day continuous support from any three, continuous view combination of the following 26-meter-diameter antenna stations: DSSs 11, 12, 41, 42, 51, 61, and 62. The launch stations for *Pioneers F* and *G* will be: DSSs 11, 42, 51, and 61. After July 1973 and during the Jupiter encounter phase the 64-meter-diameter antenna subnet (DSSs 14, 43, and 63) will provide the best assurance for near-optimum data return using the network's most advanced resources.

Because of Jupiter's position versus the inclination of the Earth's spin axis, the geocentric declination angle of the *Pioneer F* mission will be quite low, at least during the first part of the Jupiter transfer trajectory. Figure 6 depicts the relationship between geocentric declination versus time after orbit injection. At injection, the geocentric declination angle is approximately minus 32½ degrees, and at Jupiter encounter the declination is minus 19 degrees. Because of the low negative declination angles, the view of the spacecraft from the DSN stations located in the southern hemisphere is more favorable than the view from the northern hemisphere locations. Figure 7 shows the typical view periods for a February 29, 1972 launch date versus the elevation angles of the corresponding antennas. The first acquisition station's (DSS 51) set time is approximately 2 hours before the Ascension station loses view of the spacecraft. There is a small time gap between DSS 51 (Johannesburg) set and DSS 11 (Goldstone) rise. It is planned that during this gap the Ascension station will deliver the telemetry information. The view period of DSS 11 is in the vicinity of 7 hours, but the view period of DSS 42 at Canberra, Australia, is more than 14 hours long and there exists also a good overlap between DSS 51 (Johannesburg) rise and DSS 42 (Canberra) set.

The lengths of the view periods of the northern hemisphere stations are increasing gradually. One hundred days after launch the declination angle decreases from minus 33 degrees to minus 24 degrees. As shown in Fig. 8, DSS 11 at Goldstone has at that time a maximum view period of almost 10 hours.

The low elevation angles of the northern hemisphere stations connected with short station overlaps, as shown between DSS 51 in Johannesburg or DSS 61 at Spain versus DSS 11 at Goldstone, can, during a few hours, cause a deterioration of the signal-to-noise ratio of the telemetry signal. The typical telemetry degradation factors versus 13- and 8-degree elevation angles are given. At Jupiter encounter the DSN plans to use the 64-meter-diameter antenna subnet. DSS 14 is located at Goldstone, DSS 43 at Canberra, Australia, and DSS 63 at Madrid, Spain. The closest approach to Jupiter with a spacecraft/Jupiter center range of 3 Jupiter radii equivalent of 210,000 kilometers will be adjusted such that this periapsis point will be reached around the middle of the 5-hour overlap between the Goldstone and Australian stations. Thus, the most important event of the missions will be supported by two 64-meter-diameter antenna stations. This configuration will enhance the reliability of data return.

Because of the large relative velocity changes between the Earth and the spacecraft, the uplink doppler shifts are much larger than ever experienced on previous planetary flights by the Deep Space Network. Figure 9 shows the relationship between the uplink doppler shift in kilohertz versus days after spacecraft injection. The doppler shift starts at minus 70 kHz and moves between two boundaries of minus 250 kHz and plus 130 kHz. The DSN will furnish additional crystal oscillators to all stations to handle these unusual doppler excursions. Because of the large gravitational forces of the Sun's biggest planet Jupiter, the doppler shift changes from minus 250 kHz down to minus 410 kHz; and, in a few hours, it will swing back around to minus 200 kHz (Fig. 10). The DSN plans to equip DSSs 14 and 43 with special frequency synthesizers which will generate a linear frequency ramp at the predicted doppler rates. Using this equipment, the static phase error of the spacecraft receiver can be kept below 10 degrees, and the static phase error of ground station receivers will be in the vicinity of zero. This capability will provide good assurance to sustain a continuous lock of the spacecraft and ground receivers and avoid doppler cycle slipping. The latter condition could dilute the precision of the two-way Jupiter flyby doppler information necessary for the success of the Celestial Dynamics experiment.

Figure 11 shows the spacecraft geocentric radius relationship versus time from injection in days. In addition, the threshold points of the corresponding telemetry bit rates are indicated. The 26-meter-diameter antenna stations will reach the 2048-bit-per-second telemetry rate under the most favorable conditions of the S-band telecommunications link at 140 days after launch with a geocentric range of 1.3 AU. At 230 days after launch, 512 bits will be obtained, and at Jupiter encounter the 26-meter-diameter antenna stations would be able to support a 128-bit-per-second telemetry rate. The 64-meter-diameter antenna stations will increase the data return considerably. If and when these facilities can be made available for tracking and data acquisition, telemetry bits rates of 1024 bits per second can be obtained after 280 days of flight and up to 700 days. This time frame will include the Jupiter encounter. The shown optimum-type telemetry bit rates can only be obtained when the spacecraft high-gain antenna points exactly to the Earth and the DSN antenna to the spacecraft.

References

1. Siegmeth, A. J., "*Pioneer* Mission Support," in *The Deep Space Network Progress Report*, Technical Report 32-1526, Vol. II, pp. 6–17. Jet Propulsion Laboratory, Pasadena, Calif., Apr. 15, 1971.
2. Siegmeth, A. J., "*Pioneer* Mission Support," in *The Deep Space Network Progress Report*, Technical Report 32-1526, Vol. III, pp. 7–19. Jet Propulsion Laboratory, Pasadena, Calif., June 15, 1971.
3. Siegmeth, A. J., "*Pioneer* Mission Support," in *The Deep Space Network Progress Report*, Technical Report 32-1526, Vol. IV, pp. 13–21. Jet Propulsion Laboratory, Pasadena, Calif., Aug. 15, 1971.
4. Siegmeth, A. J., "*Pioneer* Mission Support," in *The Deep Space Network Progress Report*, Technical Report 32-1526, Vol. V, pp. 4–16. Jet Propulsion Laboratory, Pasadena, Calif., Oct. 15, 1971.
5. Siegmeth, A. J., "*Pioneer* Mission Support," in *The Deep Space Network Progress Report*, Technical Report 32-1526, Vol. VI, pp. 13–24. Jet Propulsion Laboratory, Pasadena, Calif., Dec. 15, 1971.

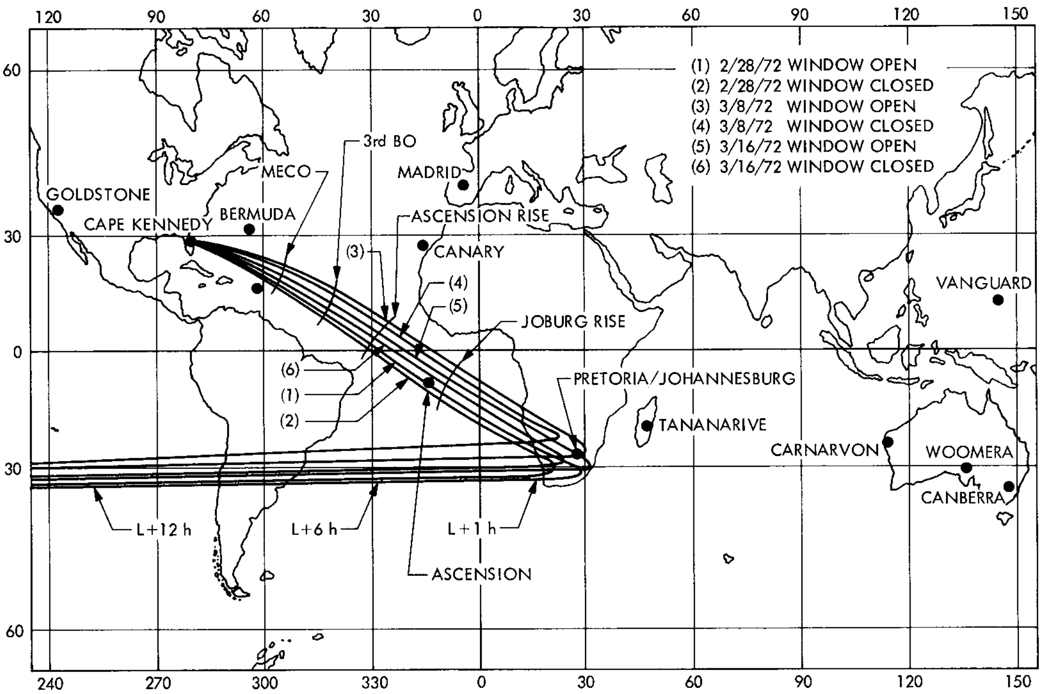

Fig. 1. *Pioneer F* Earth tracks

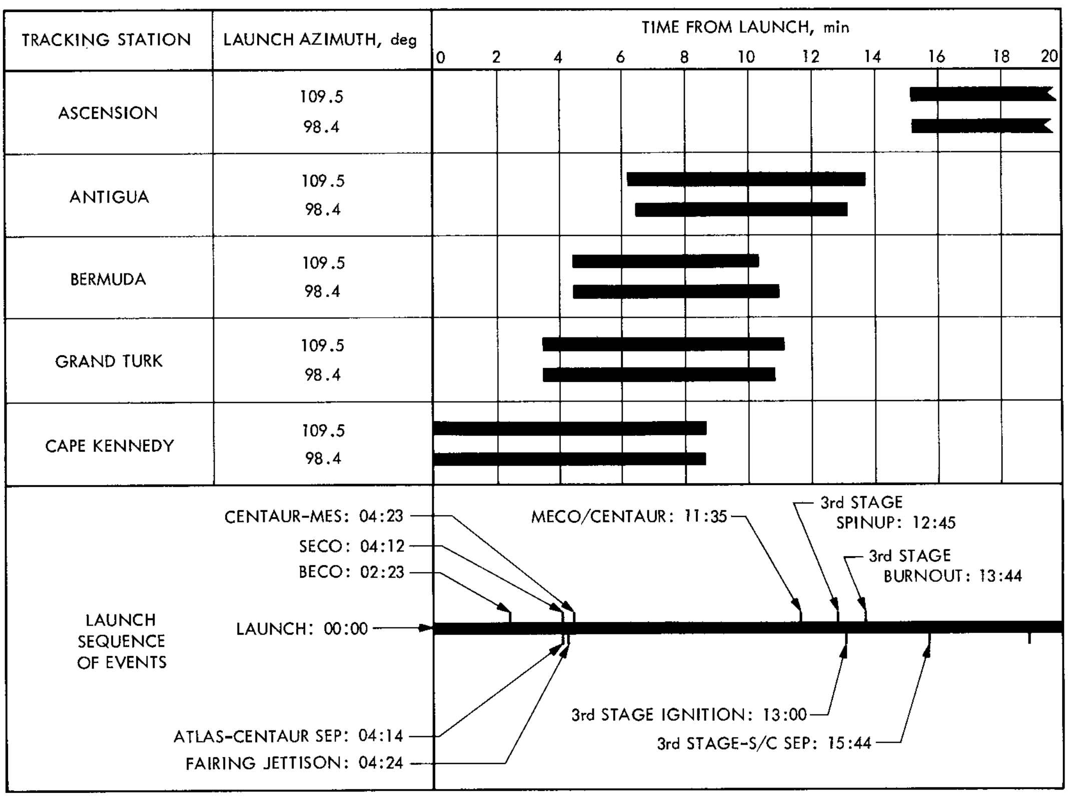

Fig. 2. *Pioneer F* nominal tracking station coverage (1-deg elevation) during powered flight

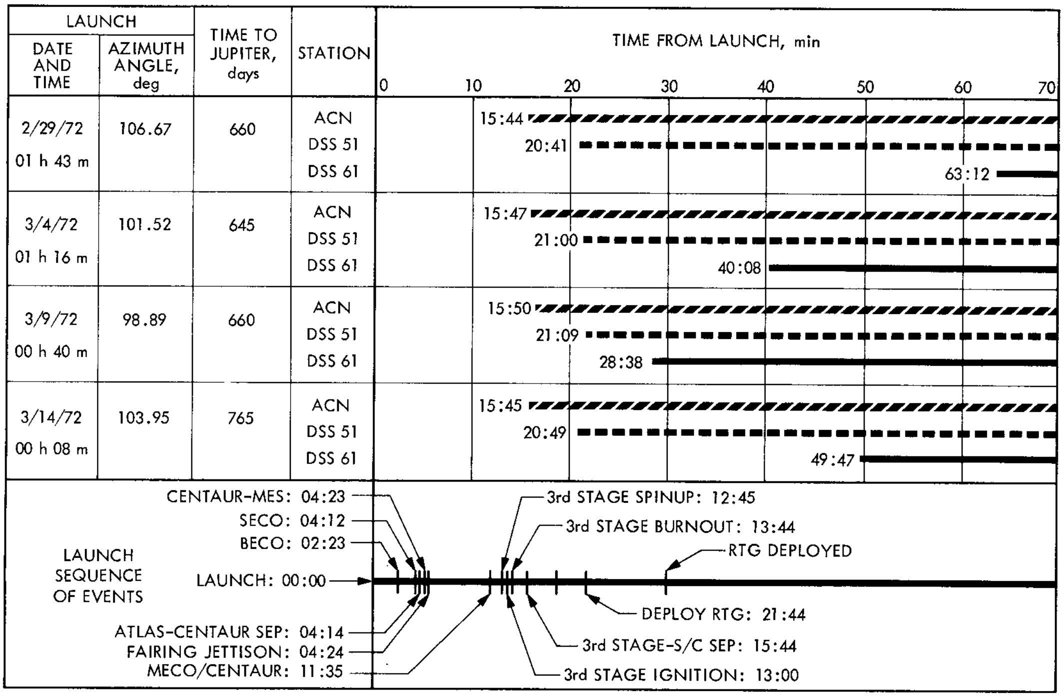

Fig. 3. *Pioneer F* first DSN acquisition typical station rise times

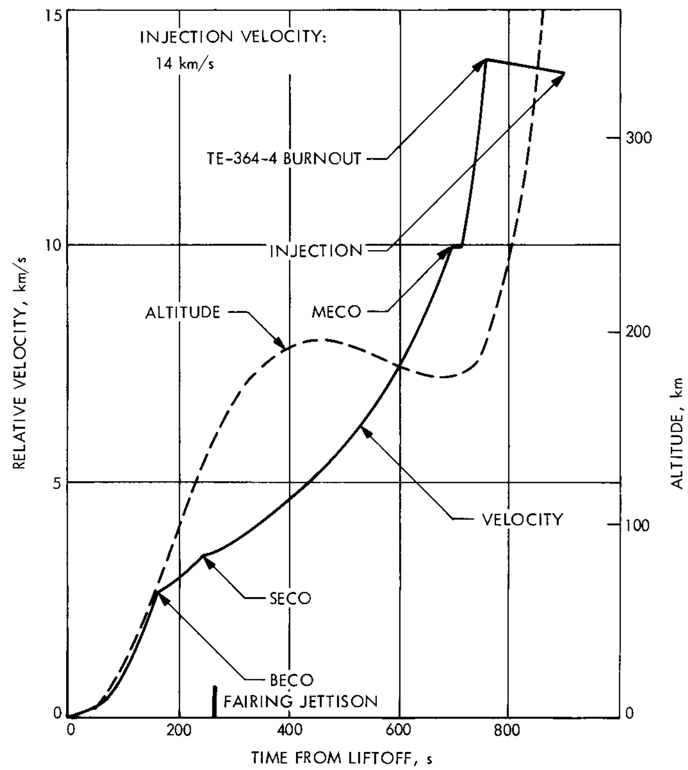

Fig. 4. Typical *Pioneer F* altitude and velocity profiles during powered flight

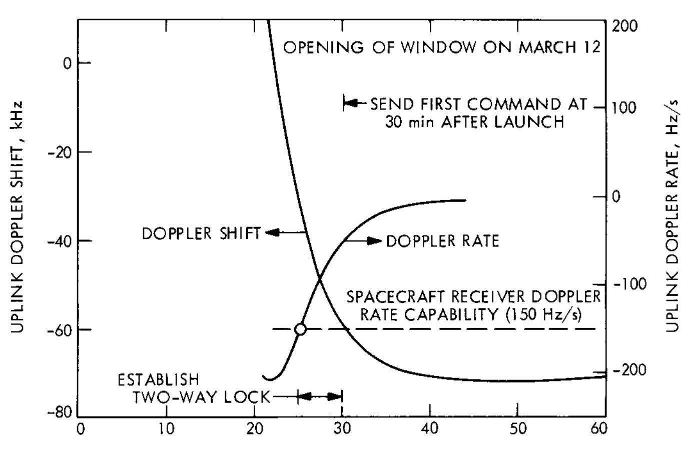

Fig. 5. *Pioneer* doppler rate at DSS 51

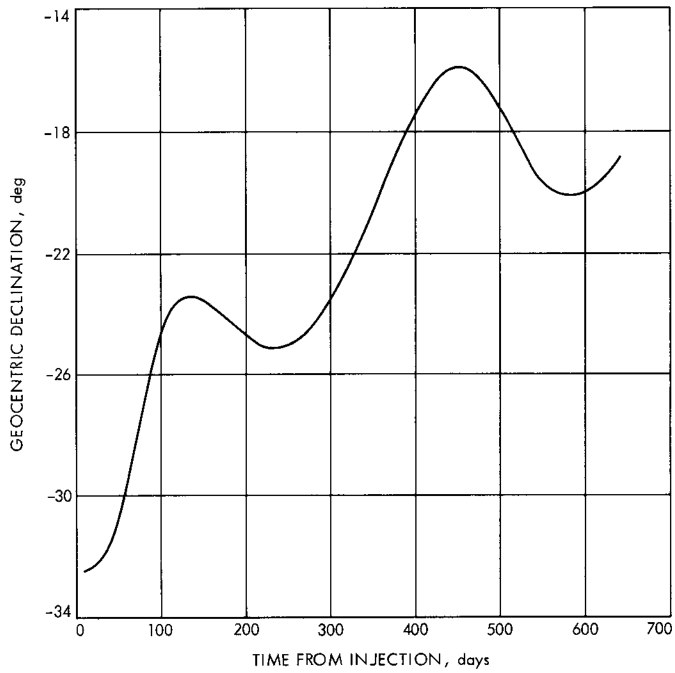

Fig. 6. Declination of *Pioneer F*

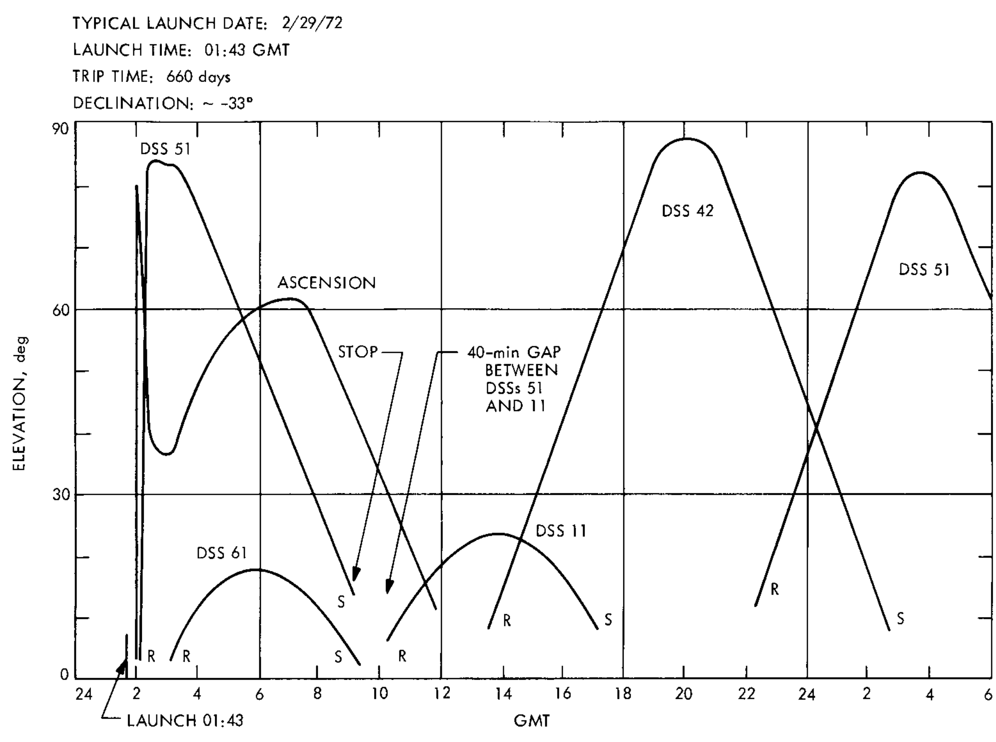

Fig. 7. DSS view of *Pioneer F* on launch day

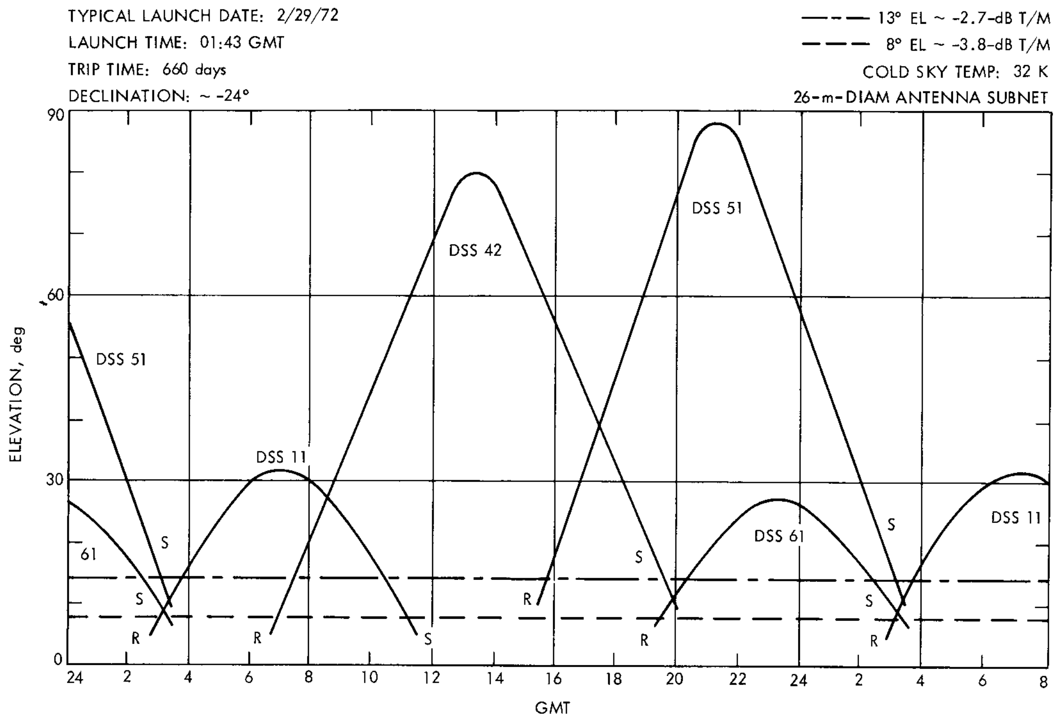

Fig. 8. DSS view of *Pioneer F* 100 days after launch

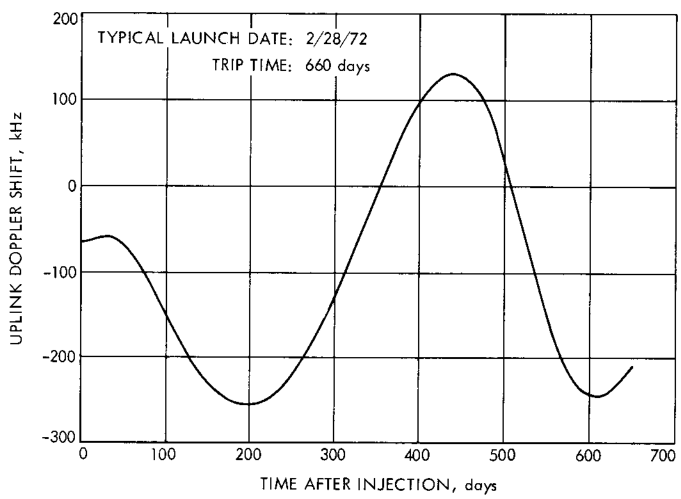

Fig. 9. *Pioneer F* uplink doppler shift between spacecraft and center of Earth

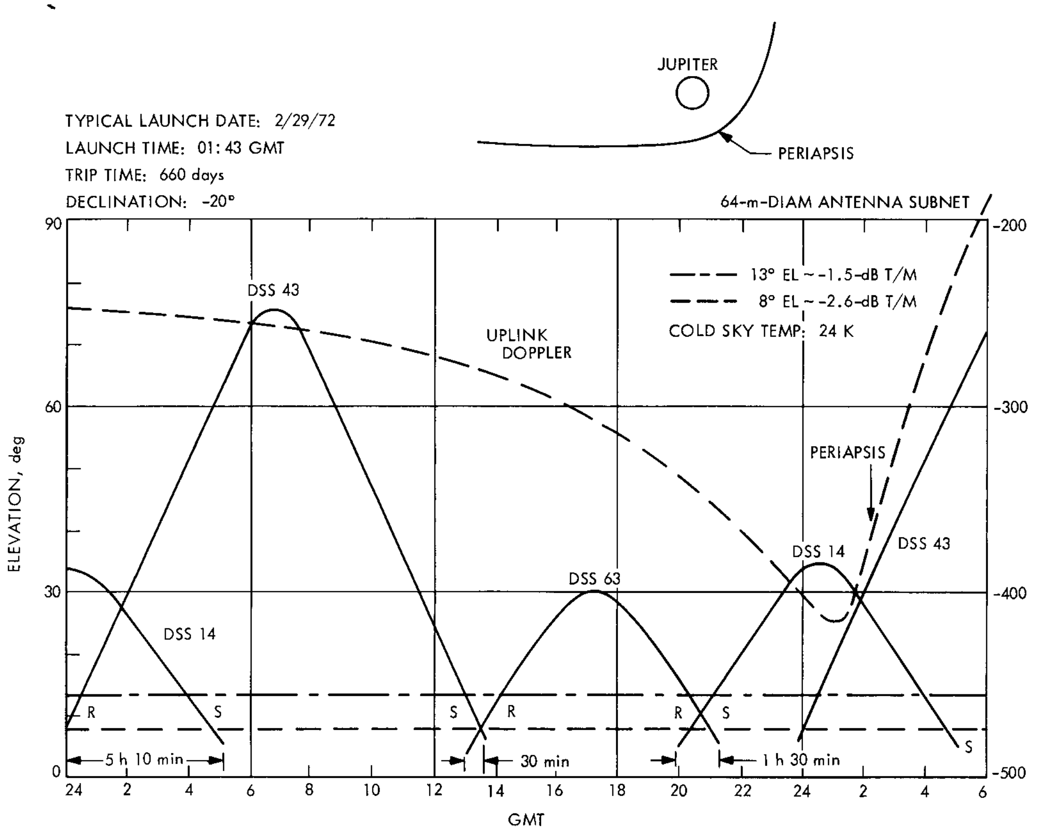

Fig. 10. DSS view of *Pioneer F* at Jupiter encounter

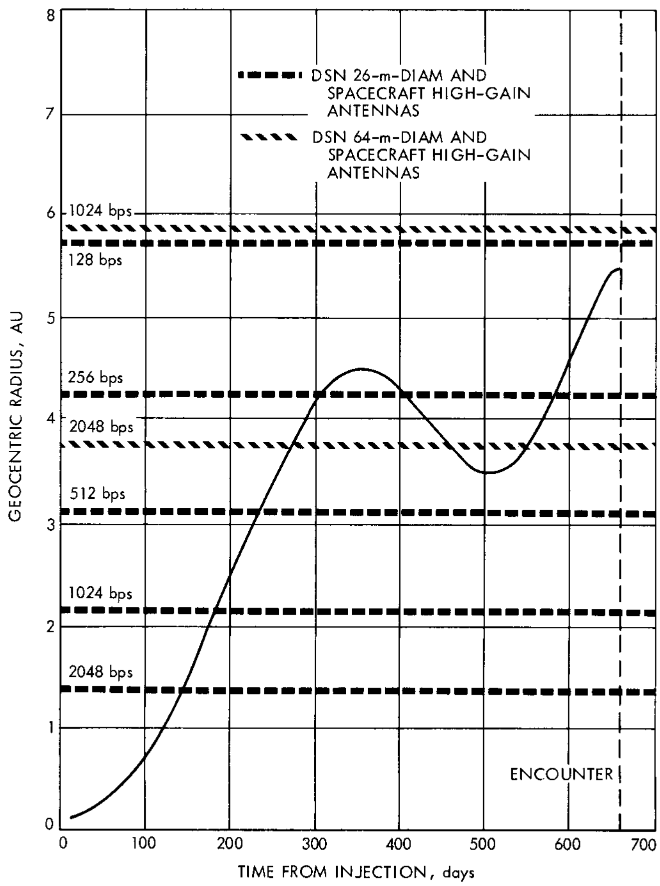

Fig. 11. Earth–*Pioneer F* distance and telemetry bit rates